

# COMPRESSION ZONE RECORDING HEAD

## BACKGROUND OF THE INVENTION

### 5           1. Field of the Invention

This invention relates to magnetic tape recording heads, and more particularly to a compression zone recording head.

### 2. Description of the Related Art

10           In magnetic storage systems, data is read from and written onto magnetic recording media utilizing magnetic transducers commonly referred to as magnetic heads. Data is written on the magnetic recording media by moving a magnetic recording head to a position over the media where the data is to be stored. The magnetic recording head then generates a magnetic field, which encodes the data into the media. Data is read from the media by similarly positioning the  
15 magnetic read head and then sensing the magnetic field of the magnetic media. Read and write operations are independently synchronized with the movement of the media to ensure that the data can be read from and written to the desired location on the media.

          An important and continuing goal in the data storage industry is that of increasing the density of data stored on a medium. For tape storage systems, that goal has led to increasing the  
20 track density on recording tape, and decreasing the thickness of the magnetic tape medium. However, the development of small footprint, higher performance tape drive systems has created various problems in the design of a tape head assembly for use in such systems.

In a tape drive system, magnetic tape is moved over the surface of the tape head at high speed. This movement generally entrains a film of air between the head and tape. Usually the tape head is designed to minimize the spacing between the head and the tape. The spacing between the magnetic head and the magnetic tape is crucial so that the recording gaps of the transducers, which are the source of the magnetic recording flux, are in intimate or near contact with the tape to effect efficient signal transfer, and so that the read element is in intimate or near contact with the tape to provide effective coupling of the magnetic field from the tape to the read element. The conventional head contour comprises a cylindrical or complex shape which is critical in maintaining the moving tape at the desired spacing from the head. The contact, or near contact, spacing is maintained by controlling the contour shape to "bleed", or scrape the boundary layer of air carried by the tape away and into bleed slots before encountering the transducer to prevent the tape from "flying", or losing contact with the transducer.

Alternatively, the contour is designed with a small radius and a high wrap angle so that high pressure is exerted on the head while the tension is low. However, the contour of the head must be such that the pressure exerted by the tape on the transducer is not so high that the surface of the transducer wears excessively. Heads are often provided with outriggers on both sides of the head which help support the tape and reduce head wear, but, more importantly, control the wrap angle of the tape with respect to the head. Any change in radius will change the pressure of the tape on the head at the same tape tension.

A flat contour thin film tape recording head for a bi-directional tape drive is described in commonly assigned U.S. Patent No. 5,905,613 to Biskeborn and Eaton which is incorporated by reference herein. The flat contour head comprises a flat transducing surface on a substrate having a row of thin film transducers formed on a surface on one side of the substrate which

forms a gap. The substrate with the row of transducers is called a "rowbar substrate". The transducers are protected by a closure of the same or similar ceramic as the substrate. For a read-while-write bi-directional head which requires that the read transducer follows behind the write transducer, two rowbar substrates with closures are mounted in a carrier facing one another.

5 The recording tape overwraps the corners of both substrates with an angle sufficient to scrape the air from the surface of the tape and not so large as to allow air to reenter between the tape and the transducing surface after the tape passes the corner. By scraping the air from the surface of the moving tape, a vacuum forms between the tape and the flat transducing surface holding the tape in contact with the transducing surface. At the corners of the substrates, bending of the recording  
10 tape due to the overwrap results in separation of the tape from the transducing surface for a distance that depends on the wrap angle, the tape thickness and the tape tension. The transducers must be spaced from the corners of the substrate at a sufficient distance to allow the vacuum between the tape and the transducing surface to overcome this separation.

There is an ongoing need for reduced separation of the transducers and the recording  
15 media and of improved control and reliability of this separation in order to support constantly increasing data density and speed requirements of data storage systems. The present invention provides an improved recording head to address this need.

## SUMMARY OF THE INVENTION

20 In accordance with the principles of the present invention, there is disclosed a compression zone recording head comprising a flat contour, or alternatively, a shallow contour head having a thin closure preferably formed of conducting material. The recording tape wraps over the deposited closure and after a short time wears into intimate rubbing contact with the

recording elements. The edge of the wafer holding the recording elements provides the required durable support of the recording tape. Thus, the tape contacts the recording elements in a

"compression zone" at the leading or trailing edge of the head in contrast to a conventional flat profile tape head wherein the closure has substantially the same dimensions as the substrate

5 supporting the wafer resulting in the tape flying over the recording elements in a "tack-down zone" away from the edges of the head. The compression zone recording head provides

advantages of lower flying height. In addition, using a thin film deposited closure lowers the cost of fabrication since the closure is formed in a simple thin film process and fabrication is nearly identical to slider fabrication for direct access storage devices (DASD).

10 In a first embodiment, the low flying height of the compression zone recording head is achieved by having the tape compressed on the transducer elements in the compression zone at the edge of the head. The deposited closure of hard material controls element wear and recession from the tape after prolonged use. The preferred use of conductive material to form the closure helps to control triboelectric head-tape interactions by clamping the electric potential of the

15 closure to a desired value or to an electrical feedback value.

The above as well as additional objects, features, and advantages of the present invention will become apparent in the following detailed description.

## BRIEF DESCRIPTION OF THE DRAWINGS

20 For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings. In the following drawings, like reference numerals designate like or similar parts throughout the drawings.

Fig. 1 is an end view illustration, not to scale, of a conventional read-while-write bi-directional flat contour linear tape recording head.

Fig. 2 is an end view illustration, not to scale, depicting the separation of the tape from a conventional bi-directional flat contour tape recording head.

5        Fig. 3 is an end view illustration, not to scale, of a first embodiment of a compression zone recording head.

Fig. 4 is an end view illustration, not to scale, of an end portion of the compression zone recording head of Fig. 3.

Fig. 5 is an end view illustration, not to scale, of an second embodiment of a compression  
10    zone recording head.

Fig. 6 is an end view illustration, not to scale, of an end portion of the compression zone recording head of Fig. 5.

Fig. 7 is an end view illustration, not to scale, of an end portion of a near crow-bar zone recording head.

15        Fig. 8 is an end view illustration, not to scale, of an end portion of a crow-bar zone recording head.

Fig. 9 is an end view illustration, not to scale, of an end portion of a canopy zone recording head.

Fig. 10 is a simplified diagram of a magnetic tape recorder system using the magnetic  
20    recording head of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 illustrates a prior art bi-directional read-while-write flat contour head **100**. Rowbar substrates **102** and **104** of a wear resistant material, such as the substrate ceramic typically used in magnetic disk drive heads, are mounted in carriers **105** and **106** fixed at a small angle  $\alpha$  with respect to each other. The ceramic rowbar substrates **102** and **104** are provided with flat transducing surfaces **108** and **110** and a row of transducers at the surfaces of gaps **112** and **114**. Electrical connection cables **116** and **118** connect the transducers to the read/write channel of the associated tape drive. To control the overwrap angle  $\theta$  of the tape **120** at edges **122** and **124**, outriggers **126** and **128** lapped at the desired wrap angle are provided. The wrap angle going onto the flat transducing surface is usually between 1/8 degree and 4.5 degrees. The rows of transducers are protected by closures **130** and **132** made of the same or similar ceramic as the rowbar substrates **102** and **104**.

Fig. 2 illustrates flat transducing surface **108** of the flat contour head **100** of Fig. 1. As the tape **120** moves from left-to-right or from right-to-left over the flat transducing surfaces **108**, the tape separation from the transducing surface is different in different zones across the surface. At the edges **122** and **123**, the overwrap angle results in bending of the tape to conform to the flat transducing surfaces in a narrow "compression zone" **204** where the tape is in contact with the edges **122** and **123**, the compression zone having a effective length of about 0.1-10 microns, increasing to 15-45 microns over the life of the head. By scraping the air from the surface of the moving tape, a vacuum forms between the tape and the flat transducing surface holding the tape in contact with the transducing surface; however, bending of the recording tape due to the overwrap results in separation of the tape from the transducing surface in a "canopy zone" **206** for a distance that depends on the wrap angle, the tape thickness and the tape tension and speed.

For typical values of tape tension and tape thickness and wrap angles in the range of 1/2-2 degrees, the canopy zone distance is in the range of 10-200 microns. The canopy zone **206** comprises a primary separation zone **207** and a smaller amplitude secondary separation zone **209** having a contact or near contact "crow bar zone" **211** in between. In a "tack-down zone" **208**, the vacuum between the tape and the transducing surface is sufficient to overcome this separation and the tape **120** is in contact or near contact with the flat transducing surface **108** and **110**. In the flat contour head **100**, the transducers are positioned at the gaps **112** and **114** in the tack-down zones **208** where the tape is in contact or near contact. However, intermittent tape separation caused by vibration, surface roughness or air entrainment effects results in some degradation of read and write performance of these heads.

Fig. **3** illustrates a first embodiment of a compression zone recording head **300** according to the present invention. The head **300** comprises rowbar substrates **302** and **304** of a wear resistant material, such as the substrate ceramic typically used in magnetic disk drive heads, are fixed in a carrier **306** at a small angle  $\alpha$  with respect to each other. The ceramic rowbar substrates **302** and **304** are provided with flat transducing surfaces **308** and **310**. Rows of transducers **316** and **318** are provided at the surfaces of gaps **312** and **314**. Electrical connection cables **320** and **322** connect the transducers to the read/write channel of the associated tape drive. The rows of transducers are protected by thin closures **324** and **326** made of a layer of hard, preferably conductive, material such as Al-Fe-Si (Sendust) deposited over the row of transducers, or alternatively of a layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited or bonded to the row of transducers.

Fig. **4** illustrates an enlarged portion **400** of the row substrate **302** showing detail of the row of transducers **316** and the thin closure **324** in the compression zone **204** of the head **300** of

Fig. 3. The row of transducers **316** is formed on an alumina substrate **402** deposited on the edge **404** of the ceramic rowbar substrate **302**. The closure **324** may be sputter deposited on the insulation layer **406** which protects the row of transducers **316** and is preferably formed of a layer of Al-Fe-Si having a thickness in the range of 0.1-10 microns. Alternatively, the closure **324** may be formed of a thin layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer over the row of transducers. The tape **120** wraps over the deposited closure **324** at the flat transducing surface **308** at an overwrap angle  $\theta$  and after a short run time wears into intimate rubbing contact with the recording elements of the row of transducers. The edge of the ceramic rowbar provides the necessary durable support. Thus, the tape contacts the recording elements in the so-called compression zone **204**. In contrast, in a conventional flat profile head the tape passes over the elements in the so-called tack zone away from the edges of the head.

The advantages of the compression zone recording head **300** of the present invention are a reduced tape-to-transducer spacing and lower cost of fabrication since the closure may now be formed by a simple thin film deposition process and head fabrication is nearly identical to DASD slider fabrication well known to the art. The reduced tape to transducer spacing is achieved by having the tape compressed on the elements. The deposited or bonded closure protects the elements from rapid wear and recession from the tape during use. In addition, the closure is preferably conductive to control triboelectric head-tape interactions by clamping the electrical potential of the closure to a desired value or to an electrical feedback value.

Fig. 5 illustrates a second embodiment of a compression zone recording head **500** according to the present invention. The head **500** comprises rowbar substrates **502** and **504** of a wear resistant material, such as the substrate ceramic typically used in magnetic disk drive heads, SJO920030003US1

fixed in a carrier **506**. The ceramic rowbar substrates **502** and **504** are provided with flat transducing surfaces **508** and **510** that lie in the same plane, or alternatively, are separated from one another and form a small angle (not shown) with respect to each other. Rows of transducers **516** and **518** are provided on the surfaces of gaps **512** and **514** at the outer edges of substrates **502** and **504**. Electrical connection cables **520** and **522** connect the transducers to the read/write channel of the associated tape drive. The rows of transducers **516** and **518** are protected by thin closures **524** and **526**, respectively, made of a layer of hard, preferably conductive, material such as Al-Fe-Si (Sendust) deposited over the insulation layer on the row of transducers, or alternatively, of a layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer on the row of transducers. To control the overwrap angle  $\theta$  of the tape **120** at edges of the closures **524** and **526**, outriggers (not shown) lapped at the desired wrap angle may be formed on the carrier **506** or the angle can be established using adjustable position guides. The head **500** differs from the head **300** in having the closures **512** and **514** facing out (away from each other) instead of facing in (toward each other) as is the case for the closures **312** and **314** in the head **300**. In the head **500**, the closures, and therefore the gaps of the recording elements of the transducer rows are further apart than in the head **300** design and are more susceptible to dynamic tape skew problems. The transducers **516** and **518** may be formed on opposite sides of a single wafer, thereby providing a single substrate rather than having two substrates **502** and **504**.

Fig. **6** illustrates an enlarged portion **600** of the row substrate **502** showing detail of the row of transducers **516** and the thin closure **524** in the compression zone **204** of the head **500** of Fig. **5**. The row of transducers **516** is formed on an alumina substrate **602** deposited on the edge **604** of the ceramic rowbar substrate **502**. The closure **524** may be sputter deposited over the

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insulation layer **606** on the row of transducers **516** and is preferably formed of a layer of Al-Fe-Si having a thickness in the range of 0.1-10 microns. Alternatively, the closure **524** may be formed of a thin layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer on the row of transducers. The tape **120** wraps over the deposited closure **524** at the flat transducing surface **508** at an overwrap angle  $\theta$  and after a short run time wears into intimate rubbing contact with the recording elements of the row of transducers. The edge of the ceramic rowbar provides the necessary durable support. Thus, the tape contacts the recording elements in the so-called compression zone **204**.

Fig. **7**, **8** and **9** illustrate third, fourth and fifth embodiments of the invention, respectively, wherein the locations of the row of transducers are displaced away from the compression zone **204** into the canopy zone **206** (see Fig. **2**) by increasing the thickness of the closures that are used. Fig. **7** illustrates a "near" crow-bar zone head **700** comprising a closure **702** having a thickness slightly less than the length of the canopy zone **206** so that a transducer row **704** at the gap between the closure **702** and an edge **706** of the substrate **708** is located in a region near the crow-bar zone **211** between the primary and secondary separation zones **207** and **209**. In order to locate the transducer row in the near crow-bar zone, the closure **702** has a thickness in the range of 50-200 microns depending on the wrap angle, the tape thickness and the tape tension and speed. The closure **702** may be sputter deposited over the insulation layer on transducer row **704** and is preferably formed of a layer of Al-Fe-Si, or alternatively, may be formed of a thin layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer on the row of transducers.

Fig. **8** illustrates a crow-bar zone head **800** comprising a closure **802** having a thickness slightly less than the length of the canopy zone **206** so that a transducer row **804** at the gap

between the closure **802** and an edge **806** of the substrate **808** is located at the crow-bar zone **211** between the primary and secondary separation zones **207** and **209**. In the crow-bar zone head, the transducer row **804** is located at the position of minimum clearance of the tape **120** from the transducing surface **810** between the primary and secondary separation zones **207** and **209**. In order to locate the transducer row in the crow-bar zone, the closure **802** has a thickness in the range of 50-200 microns depending on the wrap angle, the tape thickness and the tape tension and speed. The closure **802** may be sputter deposited over the insulation layer on the transducer row **804** and is preferably formed of a layer of Al-Fe-Si, or alternatively, may be formed of a thin layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer on the row of transducers.

Fig. 9 illustrates a canopy zone head **900** comprising a closure **902** having a thickness approximately half the length of the canopy zone **206** so that a transducer row **904** at the gap between the closure **902** and an edge **906** of the substrate **908** is located at or near the point of maximum separation of the tape **120** from the transducing surface **910** of the substrate **908** in the primary separation zone **207**. In order to locate the transducer row in the middle region of the canopy zone, the closure **902** has a thickness in the range of 10-200 microns depending on the wrap angle, the tape thickness and the tape tension and speed. The closure **902** may be sputter deposited over the insulation layer over the transducer row **904** and is preferably formed of a layer of Al-Fe-Si, or alternatively, may be formed of a thin layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O deposited on or bonded to the insulation layer on the row of transducers. The controlled separation of the transducer row **904** from the tape **120** is advantageous in low data recording density applications where transducer wear is a particular concern as, for example, in flexible card readers.

The near crow-bar zone head **700**, crow-bar zone head **800** and canopy zone head **900** may all be used in a configuration having the closures facing in (toward each other) as is the case for the closures **312** and **314** in the compression zone head **300** or facing out (away from each other) as in the case of closures **512** and **514** in the compression zone head **500**.

5           In the embodiments described herein above, the closures have preferably been made of sputter deposited layer of Al-Fe-Si, or alternatively of a deposited or bonded layer of Al-O-Ti-C, Zr-O-Ti, Si-N, Si-C or Zr-O. It will be understood to those of ordinary skill in the art that the closures may also be formed of other materials having the desired hardness and wear resistance.

10           In the embodiments described herein above, the compression zone recording heads comprise ceramic rowbar substrates provided with flat transducing surfaces (flat contour heads). It should be understood that heads having a shallow contour with a radius of curvature as small as 5 mm may be used with no change in the principles of operation that lead to formation of a compression zone, a canopy zone and a tack-down zone as described with respect to flat contour  
15 heads.

Fig. **10** illustrates an embodiment of a magnetic tape recorder or tape drive system **1000** incorporating the compression zone recording head of the present invention. A tape drive control unit **1002** provides a motor control signal to rotate tape reels **1004** and move magnetic tape **1006** across the read/write transducer head **1001**. Read/write channel **1008** transmits read/write signals  
20 between the read/write transducer **1001** and the control unit **1002**. The data is communicated through I/O channel **1010** with host **1012**. Lateral positioning of the transducer **1001** with respect to the tape **1006** is accomplished by positioning actuator **1014**. The lateral repositioning is required to access the various tracks of the tape **1006** with the transducer **1001**. A servo

system may be employed for accurate lateral repositioning of the transducer **1001**. An exemplary servo system includes a servo detector **1016** to detect both the track that the head is currently on and whether the head is off center. Control unit **1002** indicates the track address of a desired new track to position error detection controller **1018** for repositioning the head. Servo  
5 detector **1016** indicates the current track to position error detection controller **1018**, and the controller provides a servo position error signal to positioning actuator **1014** which repositions the transducer **1001** to the new track. The servo system also provides track following signals to positioning actuator **1014** so that the tracks on tape **1006** may be closely spaced.

While the present invention has been particularly shown and described with reference to  
10 the preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit, scope and teaching of the invention. Accordingly, the disclosed invention is to be considered merely as illustrative and limited only as specified in the appended claims